EEL 6509 Wireless Communications– Fading

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1 Overview

- Fading
  - Review: Time Dispersion Parameters
  - Frequency Dispersion Parameters.
  - Classification (Types of Fading)
  - Rayleigh & Rician Distributions
  - Clarke's/Jakes Fading Model

2 Time Dispersion Parameters

- based on power delay profile (PDP)
- mean excess delay, $\overline{\tau}$ = mean delay of PDP
- RMS delay spread = σ_τ = standard deviation of PDP
- coherence bandwidth = $B_C \propto \frac{1}{\sigma_\tau}$

3 Frequency Dispersion Parameters

Doppler Spread, $B_D = f_m$

- measure of spectral broadening
- equal to max. Doppler shift = $\frac{v}{\lambda}$

Coherence Time, T_C

- measure of time duration over which channel impulse response is ≈ constant
- Loose approximation,

$$T_C \approx \frac{1}{f_m} \tag{1}$$

- For time correlation > 0.5,

$$T_C \approx \frac{9}{16\pi f_m} \tag{2}$$

- Rule of thumb used for modern digital comm., T_C = geometric mean of 1 and 2,

$$T_C \approx \sqrt{\frac{9}{16\pi f_m^2}} \approx \frac{0.423}{f_m}$$

4 Classification of Fading

- depends on nature of transmitted signal with respect to characteristics of channel
- 2 difference (and indep.) fading effects:

1. Multipath delay spread leads to time dispersion and frequency-selective fading

   2 possibilities:

Flat Fading	Freq. Selective Fading
BW of signal < BW of channel	BW of signal > BW of channel
Delay spread < Symbol period	Delay spread > Symbol period

2. Doppler spread leads to freq. dispersion and time-selective fading
   Again, 2 possibilities:

Fast Fading	Slow Fading
High Doppler spread	Low Doppler spread
Coherence time < Symbol period	Coherence time >> Symbol period

- time dispersion and freq. dispersion are caused by independent propagation mechanisms

4.1 Effects due to multipath Delay

1. Flat Fading

- channel response has flat gain and linear phase over BW that is > signal BW
- spectral characteristics of signal are preserved over time

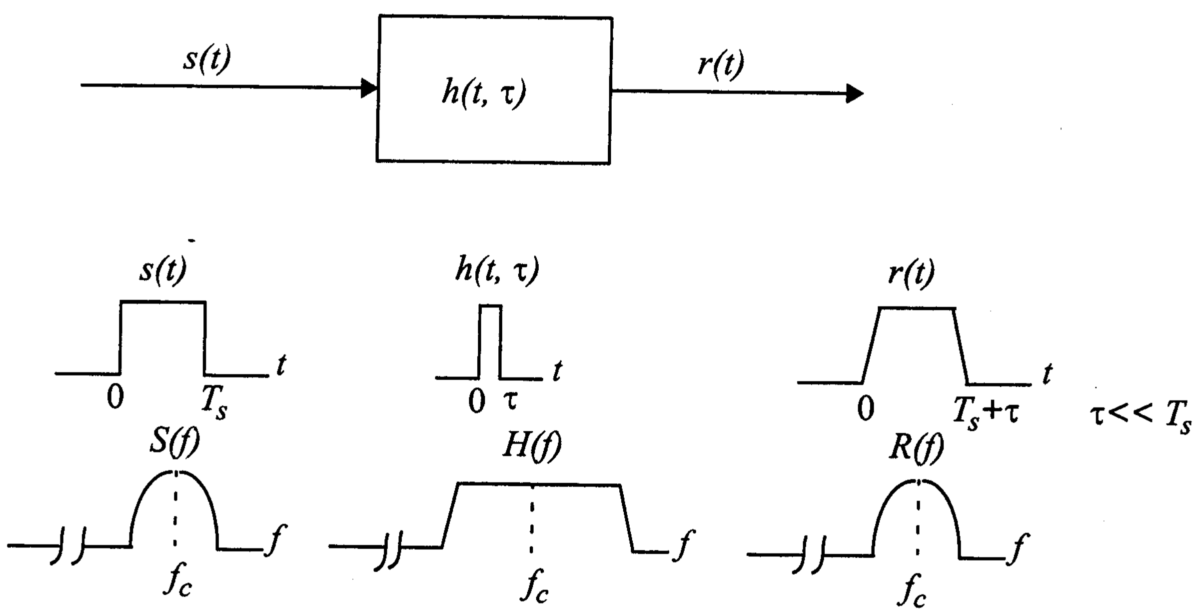


Figure 4.12
Flat fading channel characteristics.

Rappaport, p. 168

- gain of signal varies over time
- flat fading channels are also known as *amplitude varying channels* and *narrowband channels* (signal BW is narrow compared to channel BW)
- signal undergoes flat fading if

$$B_S << B_C$$

and

$$T_S >> \sigma_\tau$$

2. Frequency Selective Fading

- BW over which channel has constant gain and linear phase $<$ BW of signal
- caused by *intersymbol interference*, where received signal consists of multiple delayed and attenuated versions of transmitted signal

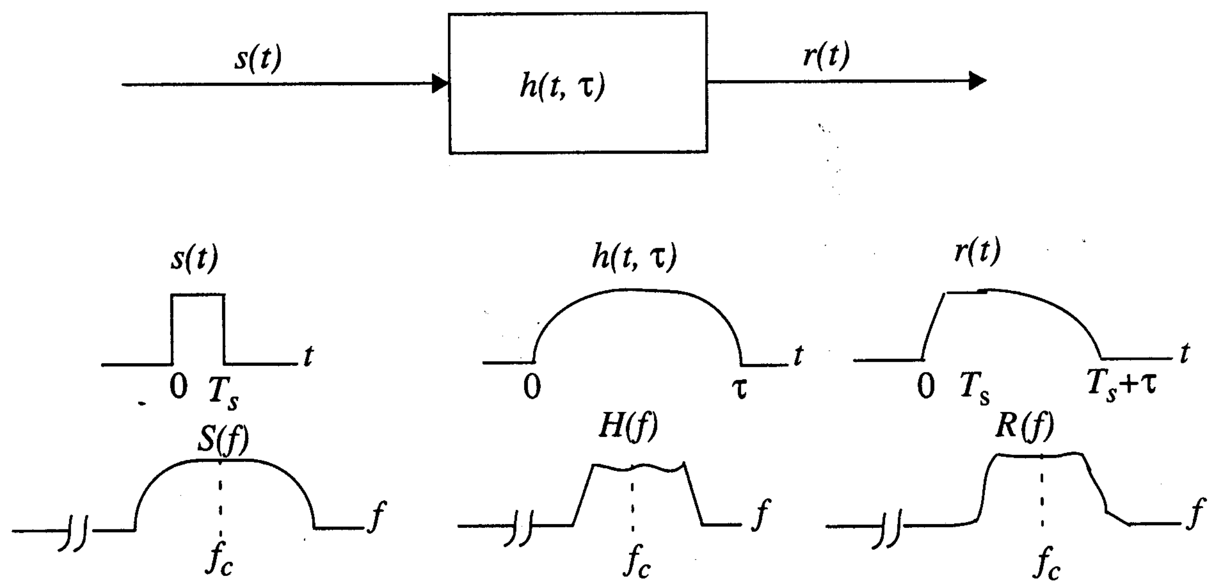


Figure 4.13
Frequency selective fading channel characteristics.

Rappaport p. 170

- signal undergoes freq.-selective fading if

$$B_S > B_C$$

and

$$T_S < \sigma_\tau$$

- Rule of thumb: channel is freq.-selective if $T_S \leq 10\sigma_\tau$

4.2 Effects due to Doppler spread

1. Fast fading
   - channel impulse response changes rapidly within symbol duration
   - occurs if $T_S > T_C$, $B_S < B_D$
   - in practice, only occurs for very low data rates
2. Slow fading
   - impulse response changes much slower than transmitted signal
   - occurs if $T_S << T_C$, $B_S >> B_D$

5 Fading Distributions

5.1 Rayleigh Distribution

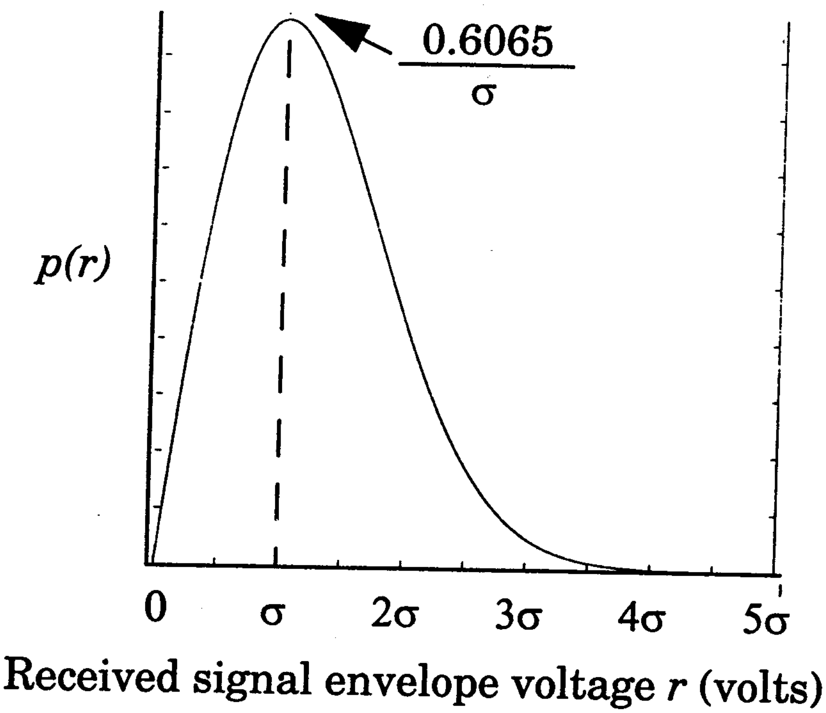
- used to model envelope of received signal or individual multipath component as random variable or random process
- used when no line-of-sight or other dominant non-fading path exists
- used for flat fading

Rayleigh PDF:

$$p(r) = \begin{cases} \frac{r}{\sigma^2} \exp\left\{-\frac{r^2}{2\sigma^2}\right\}, & 0 \le r < \infty \\ 0, & r < 0 \end{cases}$$

σ^2 = avg. power of received signal before detection

Rappaport, Fig 4.16, p. 174
Rayleigh PDF



Rappaport
p. 173

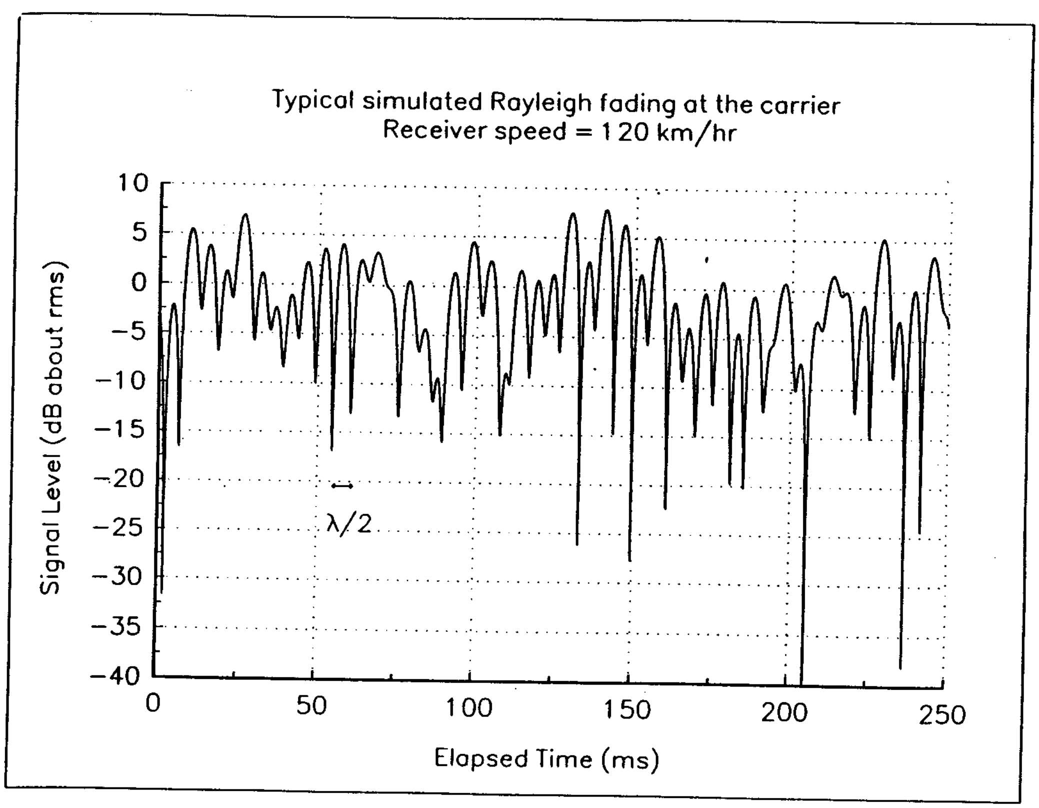


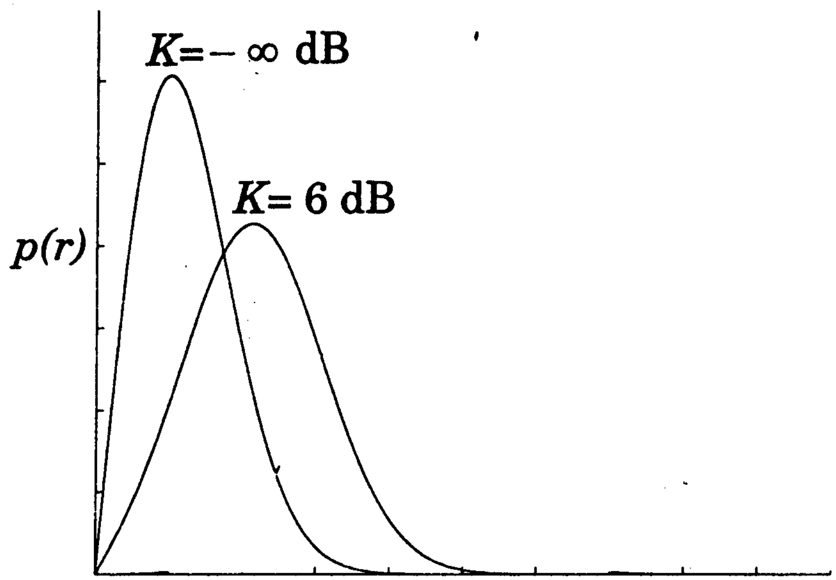
Figure 4.15
A typical Rayleigh fading envelope at 900 MHz [From [Fun93] © IEEE].

5.2 Rician Distribution

- used when LOS path or other dominant non-fading path exists
- characterized by Rician factor K that compares signal power in nonfading path to variance of multipath
- For $K \to -\infty$ dB, Rician $\to$ Rayleigh

Rician density:

Rappaport Fig 4.18, p. 176



Received signal envelope voltage *r* (volts)

6 Clarke's Model for Flat Fading

- models received signal as N plane waves with equal amplitudes and arbitrary phases and azimuthal angles of arrival
- each wave undergoes Doppler shift dependent on velocity and angle of arrival
- resultant signal envelope is Rayleigh random variable
- Doppler power spectrum of an unmodulated wave:

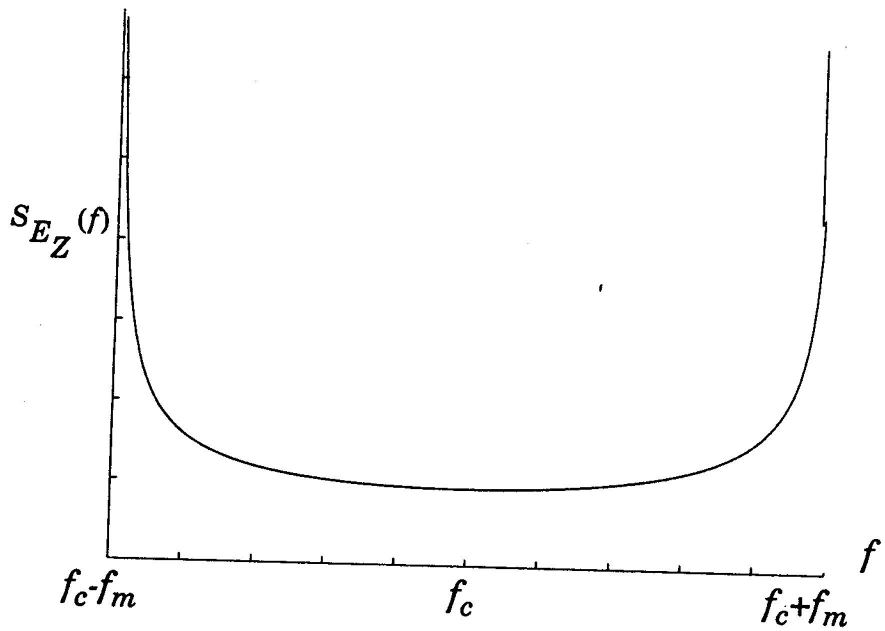


Figure 4.20
Doppler power spectrum for an unmodulated CW carrier [From [Gan72]] © IEEE].